Preparing for LHC Physics

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LHC accelerator and detectors are being installed — plan is for first collisions in "summer of 2007".

Commissioning will take time: initially just 43/2808 bunches. Hope for $\lesssim 100\,\mathrm{pb}^{-1}$ in 2007. But need to start getting ready now....

Topics:

- NLO QCD corrections to $b\bar{b}H$ [Sally Dawson, Chris Jackson]
- NNLO QCD corrections to $Z \to \ell^+\ell^-$ [Bill Kilgore].
- SUSY phenomenology – separate talk [Tadas Krupovnickas].
- Preparations for ATLAS physics [F.P.; see also Kyle Cranmer]

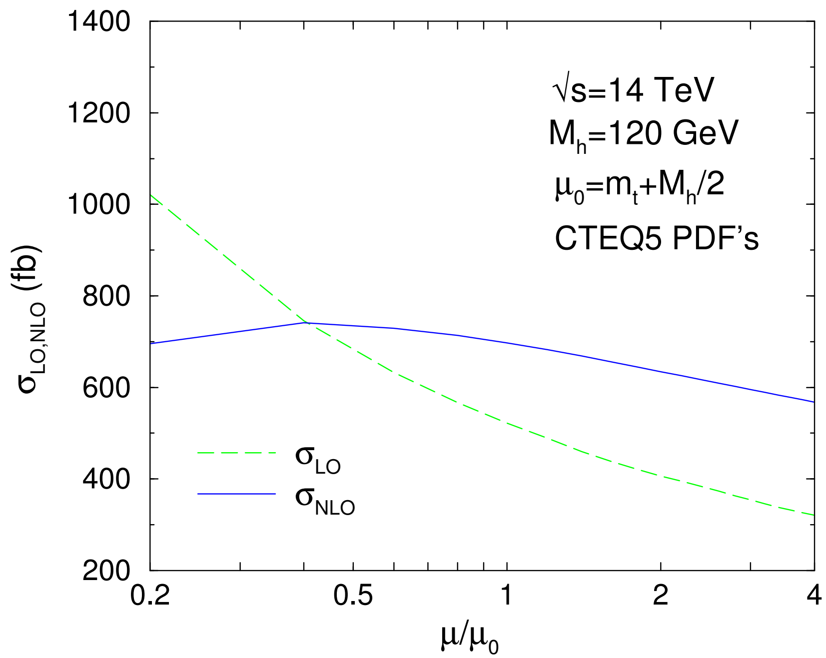
NLO $b\bar{b}H$ Corrections

Cross section for $b\bar{b}H/A$ is enhanced for $\tan\beta \gg 1$. Decay $H/A \to \tau^+\tau^-$ also enhanced. Not early physics but potentially important.

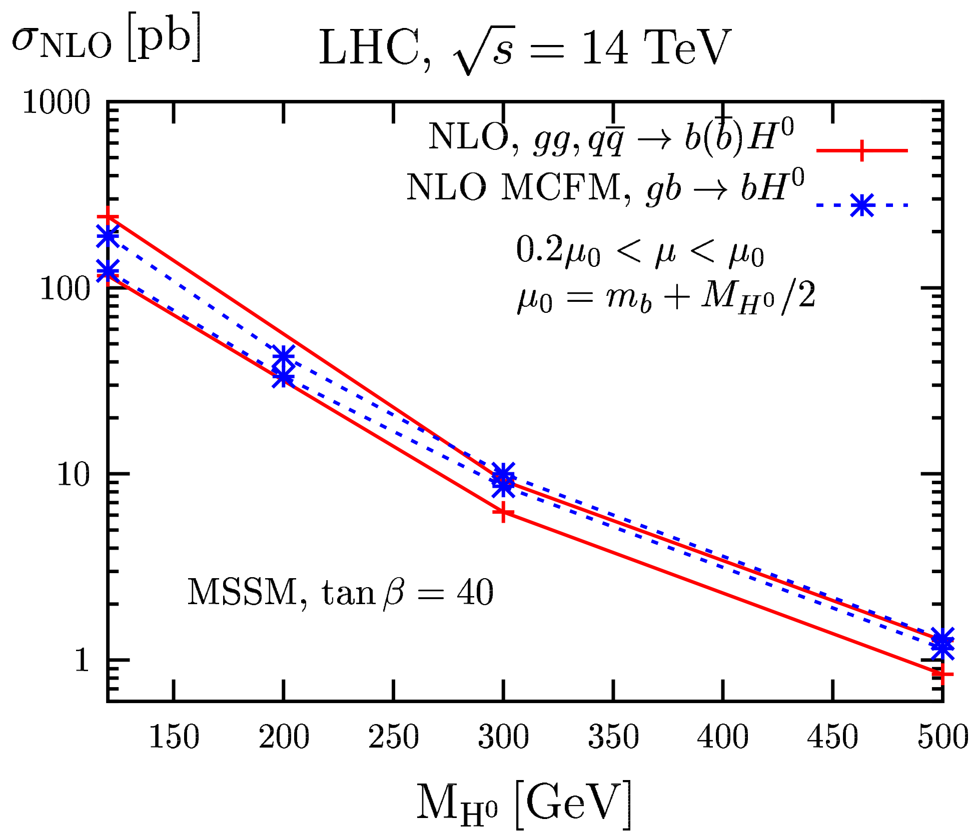
Calculation [Dawson, Jackson, Reina, Wackeroth] extends previous work on $t\bar{t}H$. Compute one-loop corrections to $gg \to b\bar{b}H$ (massive pentagons) and corresponding real emission processes. Essential for double b tag.

Much reduced scale dependence – NLO result looks reliable.

Note choice of relatively low scale improves convergence. Confirms previous conjecture.

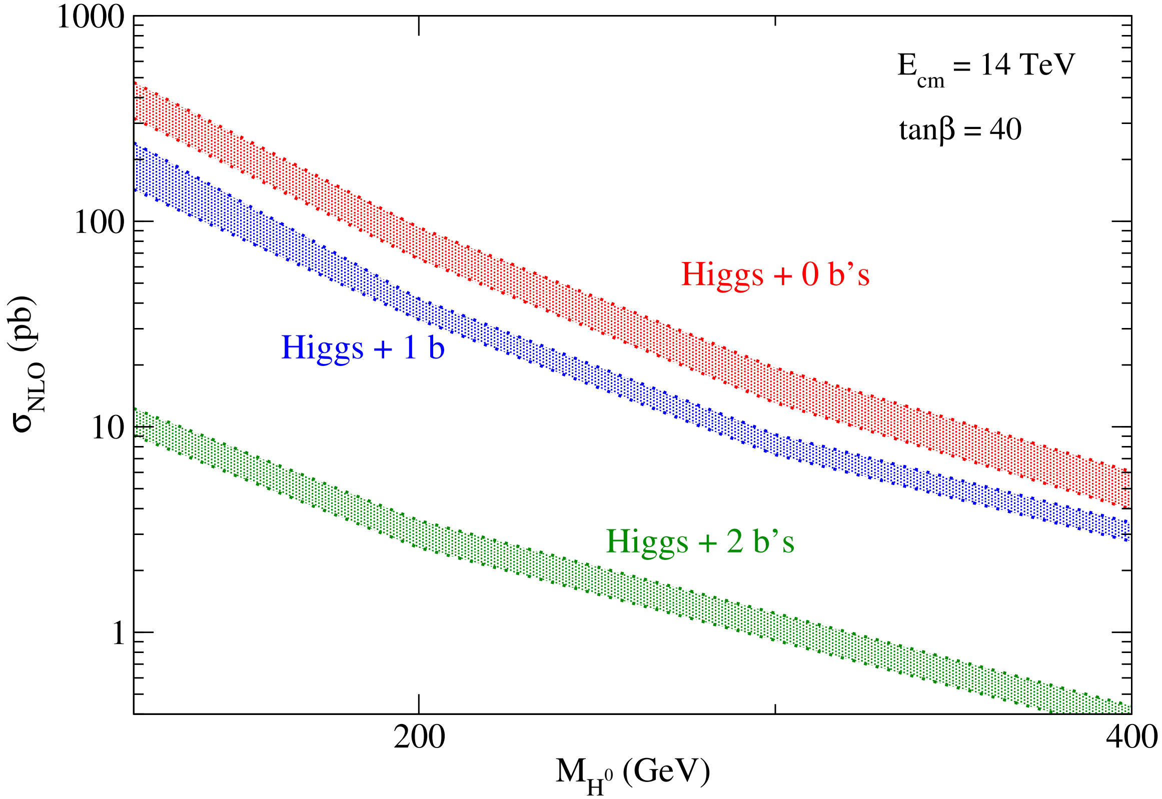


For single b tag can treat process as $gb \to Hb$. Much simpler calculation available in MCFM [Campbell, Ellis]. Require $p_{T,b} > 20\,\mathrm{GeV}$, $\eta_b < 2.5$ and compare:



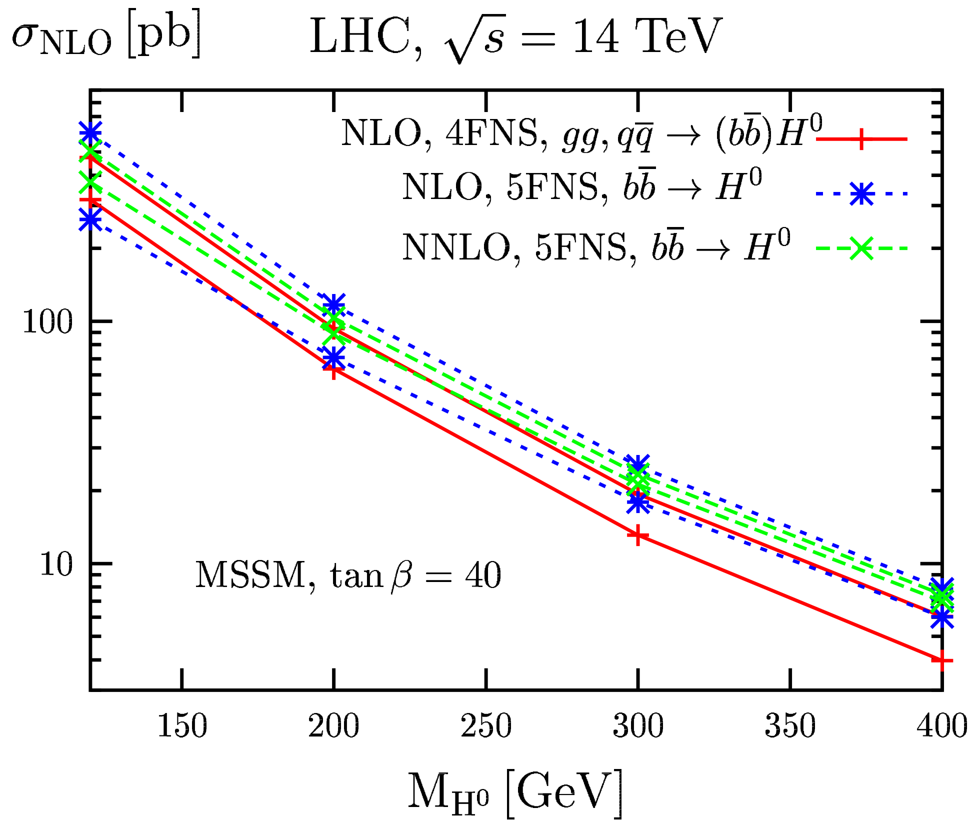
Very good agreement.

Requiring second *b* tag reduces cross section by an order of magnitude:



Double tag is not used in ATLAS analysis. Might be useful cross check.

Can also compare inclusive rate without b tag with NNLO calculation [Harlander, Kilgore]. Good agreement between NLO-corrected $gg \to b\bar{b}H$ and NNLO-corrected $b\bar{b} \to H$:



Conclusion: cross section is under good control.

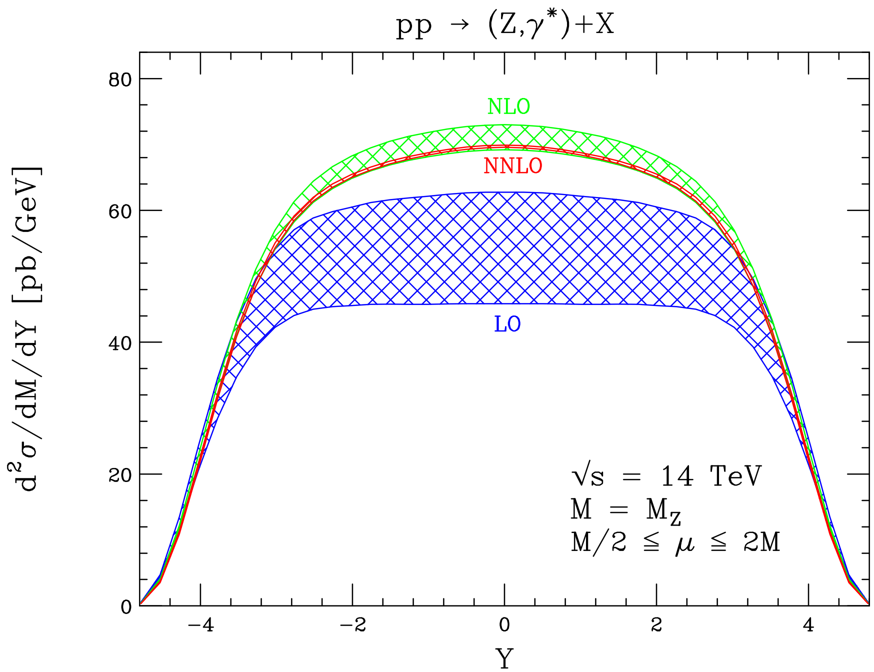
NNLO $W \to \ell\nu$ and $Z \to \ell^+\ell^-$ Corrections

$W \to \ell\nu$ and $Z \to \ell^+\ell^-$ will be early LHC physics: expect $\sim 10^5$ Z and $\sim 10^6$ W events for $100\,\mathrm{pb}^{-1}$. Crucial for calibration and for luminosity determination — traditional methods difficult at LHC energies.

Integrated cross section was first NNLO calculation for pp.

Extended to $d\sigma/dy$ with clever trick [Anastasiou, et al.]. But not enough to calculate acceptance.

Need full production/decay distribution to determine acceptance and hence luminosity.



Calculation [Bill Kilgore] uses extension of NLO subtraction:

$$\begin{aligned}
\sigma_{\text{NLO}} &= \int_{n+1} d\sigma_R + \int_n d\sigma_V \\
&= \int_{n+1} \left[d\sigma_R - d\sigma_A \right] + \int_{n+1} d\sigma_A + \int_n d\sigma_V \\
&= \int_{n+1} \left[d\sigma_R|_{\varepsilon=0} - d\sigma_A|_{\varepsilon=0} \right] + \left[\int_{n+1} d\sigma_A + \int_n d\sigma_V \right]_{\varepsilon=0}
\end{aligned}$$

Compute first term numerically and second analytically.

For NNLO have double real, real-virtual, and 2-loop virtual with multiple overlapping subtractions. Exploit fact that total is finite.

Analytic part is finished: have complete expression for $d\sigma_A$ and for analytic integral. Latter can be written as $L^{\mu\nu} H_{\mu\nu}$, where $L^{\mu\nu}$ is elementary lepton tensor and $H_{\mu\nu}$ is expressed as combination of dilogarithms and elementary functions. Result for (dominant) $q\bar{q} \to ZX$ part:

Full analytic result exists, but expression is so large that single-page Postscript file was too slow to display(!).

Result gives $d\sigma/d^3 p_{\ell_1} d^3 p_{\ell_2}$. Hence can integrate with arbitrary lepton cuts. Of course result is singular if one forces, e.g., $\vec{p}_{T,\ell_1} + \vec{p}_{T,\ell_2} = 0$. Need NNLO resummation to handle this.

Remaining task is to implement numerical calculation. Not trivial: must deal with numerical cancellation of $d\sigma_R - d\sigma_A$.

Expect results well before first $Z \to \ell^+\ell^-$ is observed at LHC.

Calculation is significant advance in state of the NNLO art.

But Z production is somewhat special: double singular regions only for $p_{T,Z} = 0$. Need more new techniques for, e.g., NNLO jet cross section.

And backgrounds for new physics typically involve many partons. . . .

ATLAS Preparations for Physics

Most previous ATLAS physics studies have considered 10–100 fb^{-1}.

Now beginning Computing System Commissioning (CSC). Main goals:

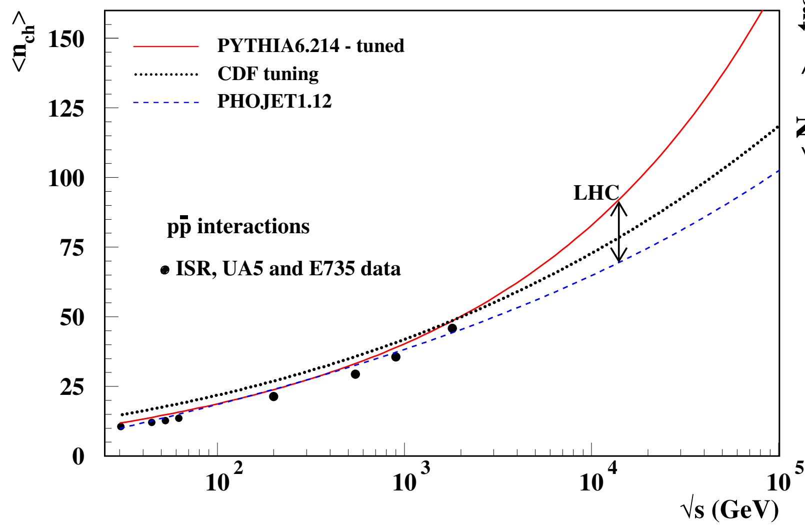
- Simulate "as-built" detector: e.g., mis-alignment of beam, solenoid, and calorimeter by few mm.
- Analysis strategy for first 100 pb^{-1}.

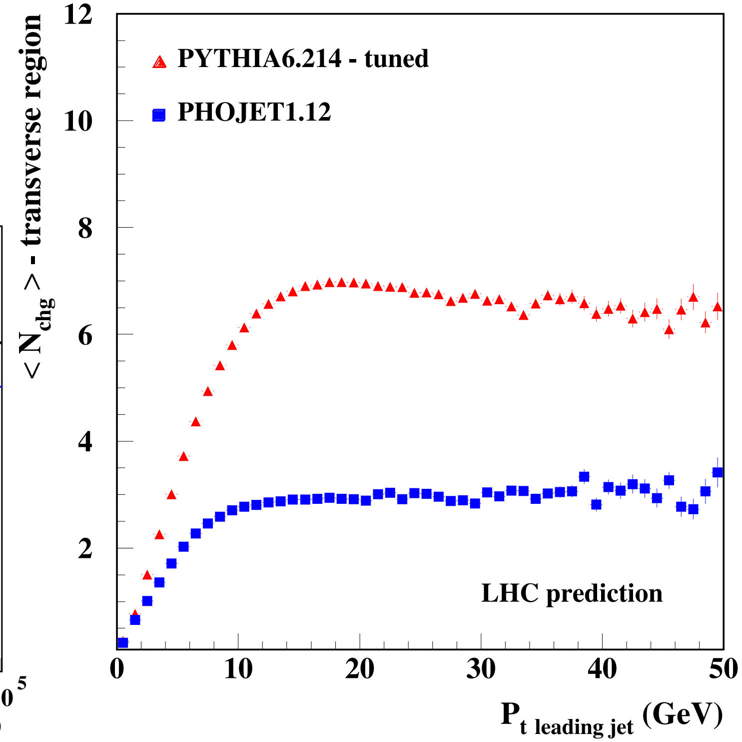
Initial luminosity unclear, but will have 100 pb^{-1} before 100 fb^{-1}.

Even 100 pb^{-1} is not small: gives about 10^5 $Z \to \ell\ell$, about 10^5 $t\bar{t}$ and perhaps 10^3 SUSY events. Major discovery is possible!

Plan to simulate with GEANT (15–30 m/event) and to reconstruct (1 m/event) about 10^7 physics events. Mainly Standard Model processes/backgrounds. Huge but necessary effort. . . .

Even tiny data sample would be useful: do not understand soft physics. Extrapolations of average multiplicity (left) and underlying multiplicity in jet events (right) [Arthur Moraes]:





Hope for much more: detector calibration, background measurement, even search for new physics. Will discuss each briefly. . . .

Calibration: ATLAS calorimeter optimized for EM resolution, driven by $h \to \gamma\gamma$. Hence hadronic response has $e/h > 1$.

Current reconstruction assumes correct EM calibration and applies H1-style correction: EM showers are dense, so $E_{\rm true} \approx E$; hadronic showers are difuse, so $E_{\rm true} > E$.

Existing calibration OK to few percent based on comparing reconstructed jets with Monte Carlo truth.

OK for discovery but not for precision measurements. Goal is $\lesssim 1\%$.

Hadronic shower simulations are not reliable. Need to test calibration *in situ* using, e.g., p_T balance between γ or $Z \to ee$ and jets, mass for $t \to q\bar{q}b, \ldots$. Work on this is just starting.

Backgrounds: For narrow peak (e.g., Z' or KK resonance) can measure backgrounds from sidebands.

SUSY is perhaps most likely early discovery physics. Cross section is $\lesssim 10\,\mathrm{pb}$, so must rely on inclusive signatures:

- $\not\!\!E_T$ plus multijets.
- $\not\!\!E_T$ plus hard dijets (e.g., from $q_R \to \tilde{\chi}_1^0 q$).
- Possibly dileptons plus $\not\!\!E_T$.

Existing analyses have estimated backgrounds using parton shower Monte Carlo plus fast detector simulation. Neither very reliable. Hence make hard cuts $\Rightarrow$ negligible SM background.

Cannot afford to do this with limited statistics.

For first time have enough fully simulated events to study background. Using multi-parton matrix element generators (ALPGEN, SHERPA).

But ALPGEN, SHERPA,... are leading order in QCD — have large scale dependence. NLO calculations of SUSY backgrounds (e.g., $Z+4$jets) not available in forseeable future.

Must measure backgrounds from data.

For $Z \to \nu\bar{\nu} + n$jets, can simply measre $Z \to \ell^+\ell^- + n$jets with small $\not{E}_T$.

$t\bar{t}$ is intermediate in difficulty [Dan Tovey].

QCD multijets are probably most difficult background to understand. Contributions both from heavy flavor ($b, c \to \nu X$) and from mismeasured jets (cracks, shower leakage, ...).

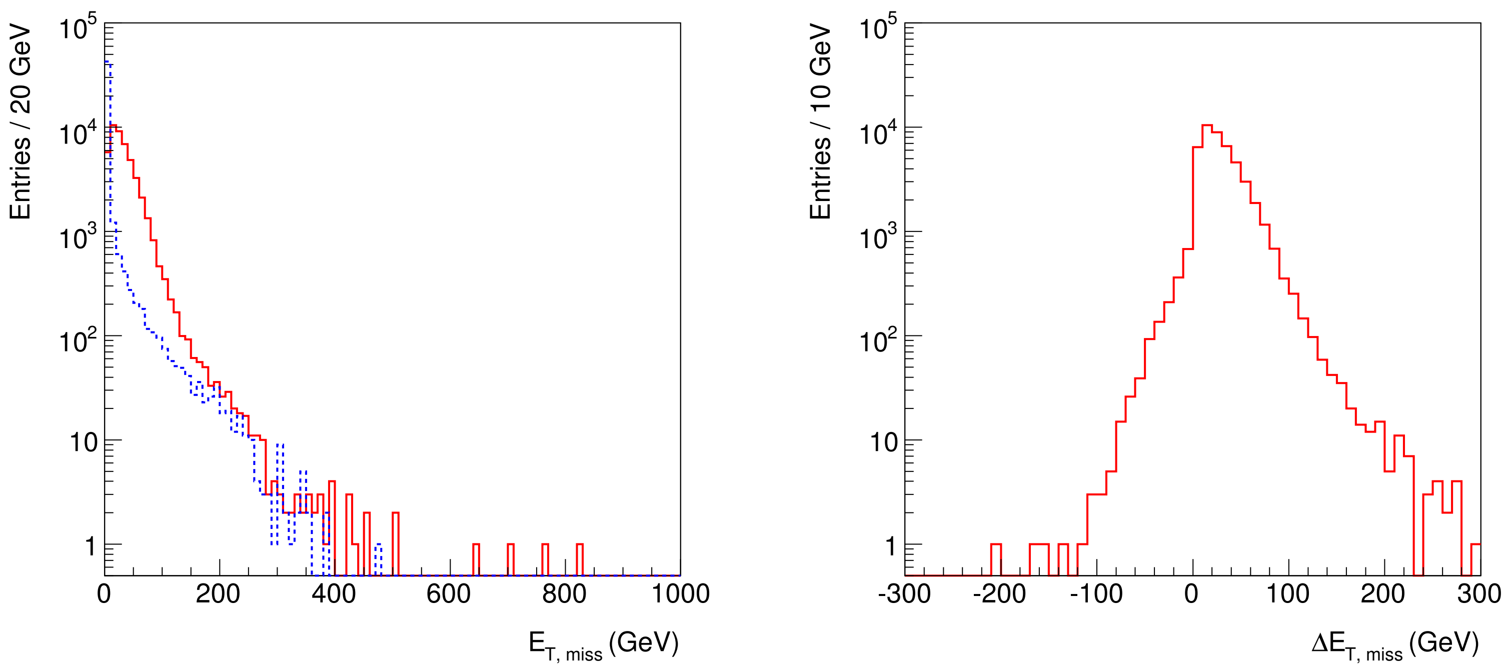
High order in α_s, so NLO calculation impossible.

Must measure samples minimizing SUSY "background":

- Multiple jets with small $\not{E}_T$;
- Coplanar dijets (and perhaps γ + jet) with large $\not{E}_T$ from crack, leakage, etc.

Then assume jet mismeasurement factorizes: combine mismeasurement probability with multijet cross section. Not easy, but for first time will have sufficient data to study problem.

Simulation of dijets of with $560 < E_T < 1120\,\mathrm{GeV}$ for $\not\!\!E_T$ (left) and $\Delta\not\!\!E_T$ (right) looks OK for $\Delta\not\!\!E_T \gtrsim 100\,\mathrm{GeV}$:



Need to verify this with real data.

Conclusion

Importance of TeV scale has been understood for at least 25 years. LHC is about to give us first data.

And yes, we need more postdocs.